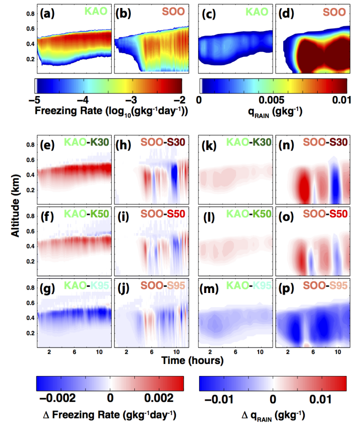
Understanding Aerosol Effects on Liquid Processes in Mixed-Phase Clouds

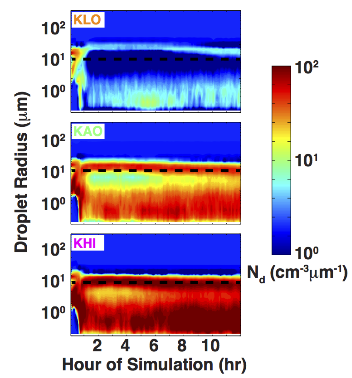
Research Highlight

Stratiform mixed-phase clouds have been shown to commonly occur and impact the surface energy budget at high latitudes (e.g., de Boer et al. 2009, Shupe et al. 2006), and cloud-induced changes to the surface energy budget have been hypothesized to contribute in modulation of sea-ice extent (Kay et al. 2008). An area of research that has only received limited attention is the influence of aerosol particle properties on mixed-phase cloud characteristics and lifetime, unlike in warm clouds, for mixed-phase clouds aerosols influence both the liquid droplet population, as well as the formation and growth of ice in the cloud. The two phases also interact, resulting in a complex combination of indirect effects. In the current work we investigate the influence of aerosol properties on mixed-phase cloud characteristics, through processes related to liquid droplets. Using a numerical model, we investigate the relative importance of aerosol properties such as soluble mass fraction, insoluble mass type, and number concentration in regulation of cloud lifetime and properties.



Domain-averaged time-height cross-sections of freezing rates for the (a) KAO and (b) SOO simulations. Also, differences between domain-averaged freezing rates in those simulations and simulations assuming different soluble mass fractions (e-j). Also plotted are domain-averaged time-height cross-sections of rain mixing ratio for (c) KAO and (d) SOO, along with differences between those values and simulations with different soluble mass fractions (k-p).

Of the aerosol properties investigated, aerosol insoluble mass type and its associated freezing efficiency was found to be most relevant to cloud lifetime. Secondary effects from aerosol soluble mass fraction and number concentration also alter cloud characteristics and lifetime. These alterations occur via various mechanisms, including changes to the amount of nucleated ice, influence on liquid phase precipitation and ice riming rates, and changes to liquid droplet nucleation and growth rates. Freezing point depression resulting from soluble material associated with aerosol particles was demonstrated to be of little importance to droplet freezing once cloud droplets were nucleated (i.e., of super-critical sizes). While the amount of soluble material likely does inhibit freezing of haze (sub-critical) droplets, this mechanism was not represented in our current model and therefore could not be quantified.



Domain-averaged cloud-top size distributions for low aerosol (72.2 cm-3), standard aerosol (350 cm-3), and high aerosol (650 cm-3) simulations at 5-minute resolution. The dashed line indicates a radius of 10 microns.

In summary, several pathways linking aerosol concentration and composition and mixed-phase cloud properties are presented. These pathways range from the impact of droplet size on in-cloud riming rate, to the influence of aerosol insoluble mass type on ice nucleation through droplet freezing, to impacts of aerosol properties on rain production within these clouds. The resulting changes to cloud properties result in large changes in surface and atmospheric energy budgets through the influence on surface radiation. It is important to remember that these results were obtained with a specific model using specific parameterizations, and that additional simulations with other models may produce different results. Having said this, with only small changes to energy budgets necessary for large impacts on things like sea ice concentration and extent (Kwok and Untersteiner 2011), these aerosol-cloud interactions have a potentially large impact on Arctic climate. While a significant amount of work to fully understand these interactions remains, the current results shed light on interesting and important mechanisms for these interactions.

Reference(s)

de Boer G, T Hashino, GJ Tripoli, and EW Eloranta. 2013. "A numerical study of aerosol influence on mixed-phase stratiform clouds through modulation of the liquid phase." Atmospheric Chemistry and Physics, 13, doi:10.5194/acp-13-1733-2013.

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Cloud Life Cycle, Cloud-Aerosol-Precipitation Interactions